

Acorn Fall and Weeviling in a Northern Red Oak Seedling Orchard¹

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Abstract In 2000, we determined levels of damage by acorn weevils (*Curculio* spp.) and patterns of acorn fall in a northern red oak (*Quercus rubra* L.) seedling orchard in eastern Tennessee. The mean (\pm SE) production of acorns among 43 selected trees was $5,930 \pm 586$ acorns per tree with a maximum production level of 16,969 acorns for one tree. Trees were selected in the spring of 2000 based on abundance of acornets. The mean (\pm SE) damage level to acorns was 33 (± 2) percent (determined by dissection). The floating method for assessing sound acorns overestimated acorn damage by 36 percent overall. Weevils accounted for approximately 66 percent of all damage to acorns. We found that the percentage of weeviled acorns was negatively correlated to total acorn production per tree. The rate of acorn drop was higher in October and November than in September. However, the percentage of acorns damaged by weevils was higher for acorns falling in September than for acorns falling in October or November.

Key Words *Curculio*, *Quercus rubra*, acorn damage, floating method

The need to regenerate stands of oaks has increased dramatically in recent years due to the impacts of oak decline and red oak borers, *Enaphalodes rufulus* Haldeman (Coleoptera: Cerambycidae) in southern forests (Starkey et al. 2004). Aside from the commercial value of oaks, acorns are critical for the maintenance of wildlife populations in many temperate forests of North America, providing a digestible high-energy food for almost 100 species of vertebrates (McShea and Healy 2002). Insects can severely reduce the availability of acorns for regeneration and wildlife, attacking acorns from almost all species of oaks (Oak 2002). In Missouri, insect damage to acorns of *Quercus velutina* Lamark, *Q. marilandica* von Muenchhausen, *Q. coccinea* von Muenchhausen, *Q. stellata* von Wangenheim and *Q. alba* L. ranged from 70 to 87% during the period of 1947 to 1952 (Christisen 1955).

Gibson (1972) reported acorn losses of 10 to 100% for *Q. alba* in forests throughout eastern North America in 1961-1964, caused primarily by the acorn weevil, *Curculio pardalis* (Chittenden) (Coleoptera: Curculionidae). Almost all species of oaks suffer damage to acorns by acorn weevils, with 22 species of *Curculio* associated with North American oaks (Williams 1989). In oak forests, adult acorn weevils generally emerge from the forest floor in August and September, climb trees, mate and lay eggs

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inside acorns (Brezner 1960). Larvae feed freely within acorns for several weeks, often with numerous larvae inside the same acorn. Larvae leave the acorns after acorns fall to the ground and burrow into the ground to depths approaching 30 cm. Larvae remain underground for approximately 2 yrs, pupate and re-emerge as adults (Solomon et al. 1980).

Acorn losses to *Q. rubra* by insects ranged from 2 to 92% in 1961-1963, 0 to 96% in 1979, and 8 to 78% in 1980 with *Curculio proboscideus* F. and *C. sulcatulus* (Casey) as the dominant species of acorn weevils (Gibson 1982). Myers (1978) found that weevils accounted for half of the 62% loss of acorns in stands of *Q. alba*, *Q. velutina*, *Q. rubra* and *Q. coccinea* in Missouri between 1973 and 1976, whereas wildlife consumed only 11%. Acorn losses to *Q. macrocarpa* Michaux to insects ranged from 6 to 97% in 1961-1964, with 94% of the damage caused by 6 species of *Curculio* weevils (Gibson 1971). Recently, Mangini and Perry (2004) documented an average acorn loss of 27% to *Curculio* weevils for *Quercus alba* in the Ozark and Ouachita National Forests in Arkansas from 1993 to 1997.

Currently, there is no control measure registered for acorn insects, although various insecticides are registered and used for the closely-related pecan, hickory and hazelnut weevils (*Curculio* spp.) (Guillebeau 2002). There is very little information on the variation of acorn damage within stands of oaks. An integrated management program for acorn weevils will need to consider issues of variation between and within forest stands. Therefore, our objective was to examine the relationships between acorn damage, magnitude of acorn crops per tree, and time of acorn fall, within a stand of mature northern red oak, *Quercus rubra*.

Materials and Methods

In the fall of 1999, we received a sample of 180 northern red oak acorns from the Watauga Seedling Seed Orchard in the U.S.D.A. Forest Service Cherokee National Forest near Mountain City, TN. The orchard was established in 1973 with 1-yr-old seedlings as an open-pollinated progeny test by the Tennessee Valley Authority and thinned in 1987 to construct a seedling seed orchard (LaFarge and Lewis 1987). The orchard was subsequently thinned in 1994, leaving approximately 750 trees (Schlarbaum et al. 1998).

The acorns constituted a random sample of acorns that had been discarded as "floaters" following the use of the floating method to detect damaged acorns. Damaged acorns are expected to float; whereas, healthy acorns are expected to sink (Korstian 1927, Olson 1974, Bonner and Vozzo 1987). All acorns were kept in separate containers to allow mature weevil larvae to leave the acorns. After 2 months, each acorn was dissected to determine damage.

In spring of 2000, 43 mature northern red oaks were selected at the Watauga Seedling Seed Orchard, based on abundance of first-year acorns (acornets). Most of the trees in the orchard had little, if any, acorn crop in 2000, necessitating our selection of trees with sufficient acorns. During the fall of 2000, all acorns falling from each tree in our experiment were collected from the ground by hand at 2-wk intervals from 7 September to 19 November, and stored at 6 to 10°C. There was no evidence of acorn losses or damage by vertebrates in the orchard. The orchard is enclosed by a 3-m fence which, in concert with an active vertebrate management program, guards against damage or losses of acorns to deer and other large vertebrates.

Acorns were counted after processing by the floating method (within 10 days of collection). Prior to floating, a sub-sample of 100 acorns was taken randomly from each tree for each collection period. All acorns in the sub-samples were dissected and examined for damage (>5% of acorn meat in cross section discolored or consumed). The lack of a pigmented sclerotized pronotal shield was used to separate *Curculio* larvae from *Conotrachelus* larvae (Gibson 1985).

Statistical analyses. Data were analyzed using the SYSTAT statistical package version 9.01 (SYSTAT 2002). Data were transformed by $\log_{10}(x)$, when residuals suggested heterogeneity, and subjected to regression analyses, paired t-tests, and one-way analysis of variance (ANOVA), followed by Fisher's least significant difference (LSD) multiple comparison test when $P < 0.05$.

Results

The mean (\pm SE) production level of acorns among the 43 selected trees in 2000 was 5,930 (\pm 586) acorns per tree with a mean (\pm SE) damage level of 33 (\pm 2)% (determined by dissection). Weevils (*Curculio* spp.) accounted for approximately 66% of all damage. The remaining damage was attributed to fungus or other insects (galls, filbertworm, etc).

In 1999, we found that the floating method employed at the Watauga Seedling Seed Orchard had overestimated the damage to acorns as 38% of the acorns in our 1999 sample were sound and not damaged. Weevil larvae (*Curculio* spp.) emerged from 50 of the acorns with an average (\pm SE) of 2.7 (\pm 0.3) larvae per acorn with a range of 1 to 8 larvae per acorn. Our results were conservative as some larvae had already emerged before we had an opportunity to place them in containers. Similarly in 2000, we found that floating overestimated damage ($t = 8.78$; $df = 42$; $P < 0.001$) by 36%. The disparity between damage levels assessed by the floating method and the actual levels of damage determined by dissection was observed in collections made after 25 September (Fig. 1). There was no significant difference between actual damage and damage assessed by floating in the first collection period of 7 to 24 September 2000.

We found temporal variation in the pattern of acorn drop among the 43 selected trees used in 2000. Acorn drop was higher in October and November than in September (Fig. 2A). Some of the variation may be explained by variation in tree phenology. Of 43 trees, 35% had maximal daily acorn drop during the period of 25 September to 8 October. In contrast, 33% of the trees had maximum daily acorn drop later in the fall (1 to 19 November). The remainder had maximum drop during 9 to 31 October. Total acorn drop was lowest for trees with maximum acorn drop in the period of 25 September to 8 October ($F = 3.63$; $df = 3, 40$; $P = 0.036$, LSD test; $P = 0.05$).

There was no significant difference among the three above-mentioned categories of trees (related to time of maximal acorn drop) with respect to acorn damage ($F = 1.52$; $df = 2, 40$; $P = 0.231$). The level of damage by weevils was directly proportional to the size of acorn crops (Fig. 3). However, the percentage of acorns infested with weevils was inversely proportional to the total number of acorns per tree, decreasing with increasing acorn crops (Fig. 4).

Weevil infestation rates were higher for acorns that fell in September than for acorns that fell in October and November (Fig. 2B). It is possible that acorns infested with weevils fall earlier than sound acorns in the same tree. There was a significant effect of collection period on the daily drop rate of weeviled acorns ($F = 6.25$; $df = 3$,

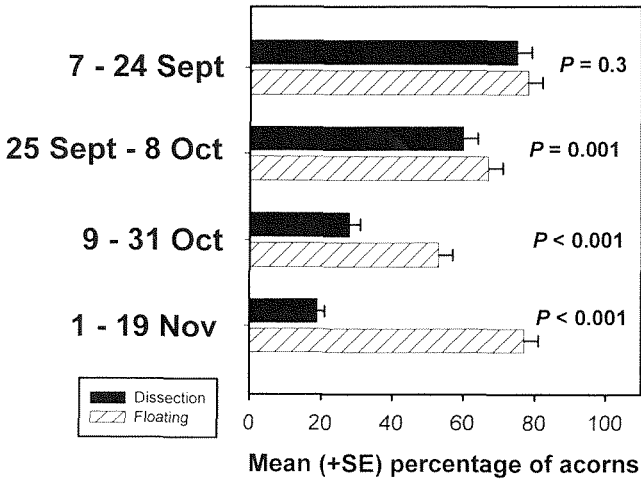


Fig. 1. Accuracy of the floating method compared to dissection of acorns in assessing damaged northern red acorns. Significance levels are for paired *t*-test.

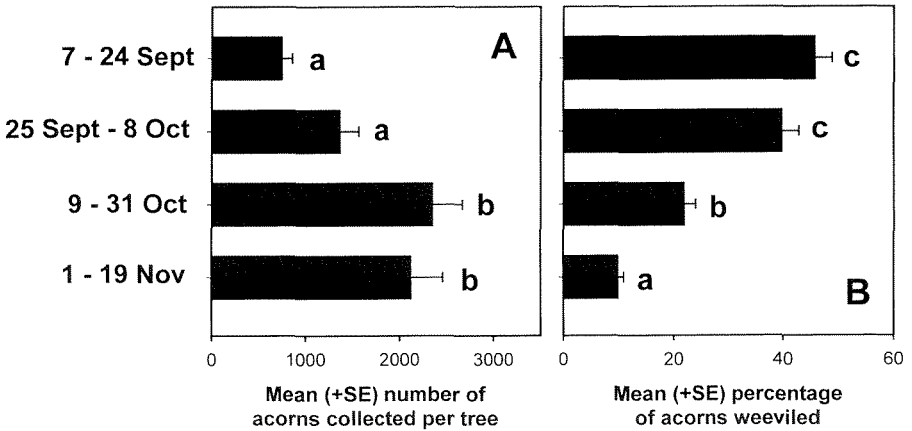


Fig. 2. Acorn production (A) and weevil damage (B) in a northern red oak seedling seed orchard in 2000. Means followed by the same letter are not significantly different at $P = 0.05$ (LSD test).

40; $P = 0.001$). Weeviled acorns fell at the highest rate from 25 September to 8 October with a mean (\pm SE) drop rate of 29.3 (\pm 2.6) weeviled acorns/tree/d (LSD test; $P = 0.05$). The lowest drop rate for weeviled acorns occurred from 1 to 19 November with a mean (\pm SE) rate of 9.3 (\pm 1.7) acorns/tree/d (LSD test; $P = 0.05$). Weeviled acorns dropped at mean (\pm SE) rates of 19.0 (\pm 2.5) and 18.3 (\pm 2.3) for the collection periods of 7-24 September and 9-31 October, respectively.

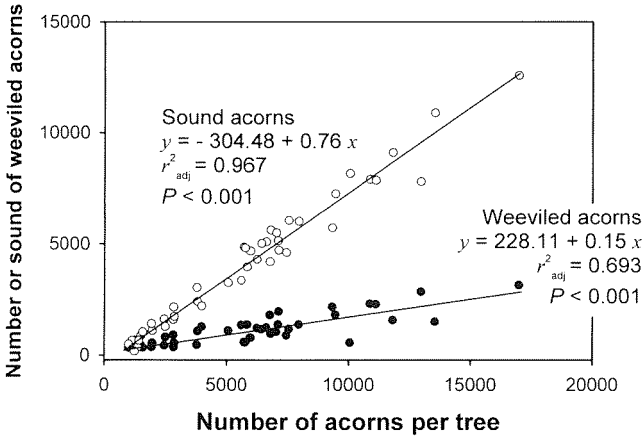


Fig. 3. Relationship of sound acorns and weeviled acorns to total acorn production.

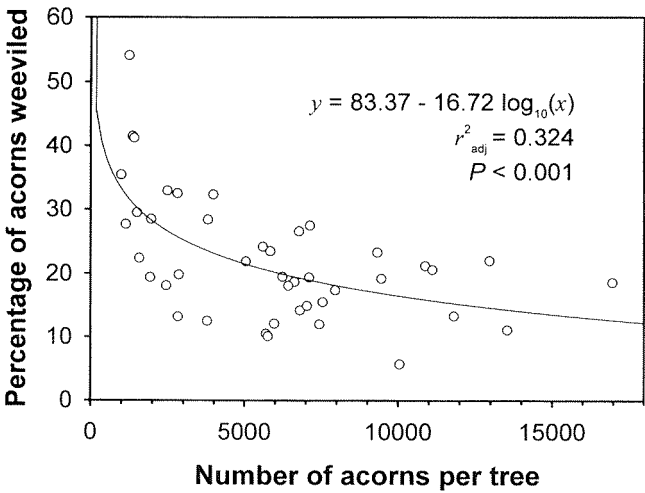


Fig. 4. Variation in weevil-caused damage over crop size of acorns.

Discussion

The possibility of increased acorn desiccation after mid-September may account for the disparity between damage estimates determined by the floating method and those determined by dissection as the likelihood of floating would increase with increasing desiccation. Gribko and Jones (1995) found that the floating method resulted in the unnecessary rejection of about 50% of sound northern red acorns from western Virginia, possibly due to genetic differences and desiccation. They further found that

12% of weeviled acorns were not detected by floating. It is possible that acorns with little feeding damage by weevils still sink. For example, Post et al. (2001) found various insect larvae in sunken northern red oak acorns collected from the Watauga Seedling Seed Orchard in 1999-2000.

Bonner and Vozzo (1987) recommend soaking acorns in water prior to determination of floaters in order to compensate for desiccation. However, some weevils bore exit holes prior to acorn fall or shortly thereafter. Soaking would result in water entering such acorns, causing them to sink in a float test. If soaking is used in a collection suspected of excessive desiccation then acorns should be visually inspected for exit holes to ensure soundness. Therefore, it seems obvious that the reliability and utility of the floating method should always be verified prior to any study or management operation.

The number of acorns infested with weevils was directly and linearly proportional to the number of acorns produced by the trees (Fig. 3). We might expect that if weevils were able to discern rich from poor patches of acorns (high vs low producing trees) then they would tend to accumulate on rich patches. The relationship would likely exhibit a tendency towards a curvilinear relationship such as a logarithmic function rather than the observed linear one. Our data suggest that weevils may not be able to discriminate trees with large acorn crops from those with small crops. The shallow linear relationship may be due to decreased search time within a patch for trees with large crops related to distance between acorns, assuming females lay multiple eggs per individual.

Alternatively, the density of female weevils may be so low that acorns are not limiting. This is possible but seems unlikely as some trees with small acorn crops had infestation rates ranging from 35 to 54%. Females may also vary the number of larvae per acorn in response to patch size. It is possible that female weevils lay more eggs in individual acorns when competition for acorns is high, as may occur when trees have low numbers of acorns or population levels of weevils are high. It is unclear if multiple larvae per acorn arise from a single female or multiple females. Brezner (1960) found an average of 1.1 larvae per northern red oak acorn in each of 2 yrs when infestation rates ranged from 22 to 24%, rates which are lower than those observed in this study.

Our results suggest that the lack of synchrony between individual trees may dampen population growth of weevils. In our study, we found that acorn production among productive trees ranged from 989 to 16,969 acorns per tree. There were likely many trees producing <1000 acorns. The population of trees at the Watauga orchard may be more diverse than a typical stand as the seedlings for the original pollination trial came from very diverse localities along the Tennessee River Valley. However, Greenberg (2000) found considerable variation among trees in acorn production for five species of oaks. It is possible that trees with low crops of acorns may receive the same number of female weevils, possibly resulting in a lower reproductive success for individual females compared to those climbing trees with large acorn crops. Considerable research is required to answer the question more fully. Issues such as the total number of eggs per female, oviposition choice and deterrents, regulation factors for weevils (such as temperature, soil moisture and predation) and interactions between insect damage and acorn phenologies need further investigation.

Additional work is also required on the impacts of weevils and other acorn insects and diseases on the germination of acorns and value of infested acorns to wildlife. An acorn with damage caused by 8 larvae, as we observed commonly in 1999, will be

unlikely to germinate. However, an acorn with damage caused by just one larva may still be viable, especially for those species of oaks, such as the white oaks, whose acorns germinate soon after dropping to the ground. It is unknown if wildlife avoid lightly damaged acorns or just heavily damaged acorns, if they avoid them at all.

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